

Description

OPTICAL ABERRATION COMPENSATOR

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The instant application is a continuation of U.S. Application Serial No. 09/995,034 filed on November 27, 2001, issuing as U.S. Patent No. 6,678,095, which claims the benefit of prior U.S. Provisional Application Serial No. 60/253,233 filed on November 27, 2000, prior U.S. Provisional Application Serial No. 60/269,114 filed on February 15, 2001, and prior U.S. Provisional Application Serial No. 60/298,259 filed on June 12, 2001. All of the above-identified applications are incorporated herein by reference in their entirety.

BRIEF DESCRIPTION OF DRAWINGS

[0002] In the accompanying drawings:

[0003] *Fig. 1* illustrates an anamorphic optical system incorporating corrector optics and a pair of prisms;

[0004] *Fig. 2* illustrates an embodiment of an anamorphic optical system incorporating a cylindrical corrector;

- [0005] *Fig. 3* illustrates an embodiment of an anamorphic optical system incorporating a cylindrical window corrector;
- [0006] *Fig. 4a* illustrates an isometric view of a variable corrector;
- [0007] *Fig. 4b* illustrates an isometric view of a variable corrector together with an associated adjusting mechanism;
- [0008] *Fig. 5* illustrates a cross-section of a variable cylindrical corrector;
- [0009] *Fig. 6* illustrates a clamp mechanism that can be used in accordance with the embodiments of *Figs. 5* and *7*;
- [0010] *Fig. 7* illustrates an embodiment of an anamorphic optical system wherein corrector optics are incorporated in the prisms;
- [0011] *Fig. 8* illustrates an embodiment of a prism at least partially filled with optical fluid, that compensates for variations in pressure or temperature;
- [0012] *Fig. 9* illustrates an embodiment of an anamorphic optical subsystem comprising three prisms;
- [0013] *Fig. 10* illustrates a projection imaging system adapted to compensate for chromatic aberration by an anamorphic optical subsystem;
- [0014] *Figs. 11a, 12a and 13a* illustrate red, blue and green image components without compensation for chromatic aberration;

- [0015] *Figs. 11b, 12b and 13b* illustrate red, blue and green image components with compensation for chromatic aberration;
- [0016] *Fig. 14a* illustrates a resulting image from the image components shown in *Figs. 11a, 12a and 13a*;
- [0017] *Fig. 14b* illustrates a resulting image from the image components shown in *Figs. 11b, 12b and 13b*; and
- [0018] *Fig. 15* illustrates a second embodiment of a projection imaging system adapted to compensate for chromatic aberration by an anamorphic optical subsystem.

DETAILED DESCRIPTION

- [0019] An anamorphic optical system provides for different magnifications in different orthogonal directions normal to an optic axis. Anamorphic lenses are most commonly used in the film industry to either compress a wide-field image into a more square frame during filming or to decompress the developed film frame upon projection. Recently the home theater industry has similarly started to use anamorphic lenses to reformat the more square, 4:3 aspect ratio of the common front-projected image into a 16:9 aspect ratio to take advantage of anamorphically compressed DVD movies. By using all the pixels of the 4:3 projector to show a 16:9 image, the image is both brighter and higher resolution than that provided by the

conventional letter box format where pixels at the top and bottom of the image are unused.

- [0020] A first known anamorphic optical system combines spherical and cylindrical lenses to preferentially magnify a beam or image in one direction. A second known anamorphic optical system uses a pair of prisms to provide this magnification while minimizing the amount of necessary deviation to the light path. These known systems, particularly the latter, exhibit anamorphic aberrations that are compounded if the focal length of the incident light varies, as may occur in home theater projection applications. A third known system using off-axis mirrors generally exhibits fewer aberrations, but generally requires relatively large mirrors which increase the size of the resulting system. These known anamorphic optical system are each an example of what is referred to hereinbelow as an anamorphic optical subsystem.

- [0021] Anamorphic optical systems are known to operate best in an afocal arrangement. There is sufficient prior art describing the use of collimation optics before and/or after the anamorphic optical system to provide this condition. This collimation condition is approximated in some applications such as home theater environments since the pro-

jected image is substantially distant from the projection lens and the aperture of the projection lens is very small relative to this distance. However, even slight deviations from ideal collimation will create astigmatic focus aberrations in the image.

- [0022] Referring to *Fig. 1*, an *anamorphic optical system* 10 comprises an *anamorphic optical subsystem* 12 in series with *corrector optics* 14. For example, an *anamorphic optical subsystem* 12 may comprise a *prismatic anamorphic optical subsystem* 12' comprising at least one prism. As known by one of ordinary skill in the art, depending upon its orientation relative to a beam of *incident light* 16, a *prism* 18, can either expand or compress the size of a beam or image. Whereas a single *prism* 18 provides for both anamorphic magnification and redirection of the beam of *incident light* 16, a pair of *prisms* 18 may be adapted to provide for anamorphic magnification without redirecting the beam of *incident light* 16.
- [0023] More particularly, the pair of *prisms* 18 comprise a *first prism* 18.1 and a *second prism* 18.2. The *first prism* 18.1 comprises *first* 19.1 and *second* 19.2 *surfaces*, wherein a *first plane* 19.1' underlying the *first surface* 19.1 intersects with a *second plane* 19.2' underlying the *second surface* 19.2 at a *first apex* 21.1. The *first prism* 18.1 further comprises a *first base bound-*

ary 23.1, wherein the first surface 19.1 comprises a first edge 25.1 that is distal to the first apex 21.1, the second surface 19.2 comprises a second edge 25.2 that is distal to the first apex 21.1, and the first base boundary 23.1 extends between the first edge 25.1 and the second edge 25.2. The first prism 18.1 further comprises at least one optical medium 27 between the first 19.1 and second 19.2 surfaces.

[0024] *Similarly, the second prism 18.2 comprises third 19.3 and fourth 19.4 surfaces, wherein a third plane 19.3' underlying the third surface 19.3 intersects with a fourth plane 19.4' underlying the fourth surface 19.4 at a second apex 21.2. The second prism 18.2 further comprises a second base boundary 23.2, wherein the third surface 19.3 comprises a third edge 25.3 that is distal to the second apex 21.2, the fourth surface 19.4 comprises a fourth edge 25.4 that is distal to the second apex 21.2, and the second base boundary 23.2 extends between the third edge 25.3 and the fourth edge 25.4. The second prism 18.2 further comprises at least one optical medium 27 between the third 19.3 and fourth 19.4 surfaces.*

[0025] *The pair of prisms 18.1, 18.2 are adapted to provide for anamorphic magnification by arranging the first 18.1 and second 18.2 prisms in a complementary relationship, so that the first apex 21.1 is aligned with the second base boundary*

23.2 and the *first base boundary* 23.1 is aligned with the *second apex* 21.2. The *first* 18.1 and *second* 18.2 *prism* in combination generate at least one aberration in the beam of light passing therethrough.

- [0026] The *corrector optics* 14 are adapted to aberrate the *incident light* 16 in a manner that at least partially compensates for at least one aberration caused by *anamorphic optical subsystem* 12, so as to reduce the amount of aberration in the beam of *exit light* 20 caused by the *anamorphic optical system* 10. For example, with the *incident light* 16 entering the *anamorphic optical subsystem* 12 after passing through the *corrector optics* 14, the *corrector optics* 14 acts to pre-aberrate the light entering the *anamorphic optical subsystem* 12 so as to reduce the resulting net aberrations in the *exit light* 20. Generally, the *corrector optics* 14 may be placed anywhere in the optical path, either ahead of or after the *anamorphic optical subsystem* 12. However, if the *incident light* 16 exhibits angular field properties rather than being unidirectional, the arrangement illustrated in *Fig. 1* would generally require smaller *corrector optics* 14 than if the *corrector optics* 14 were located after the *anamorphic optical subsystem* 12 where the light exiting therefrom could be significantly diverged.

- [0027] The *anamorphic optical subsystem* 12 is designed in accor-

dance with known principles to generally produce a desired anamorphic magnification of the *incident light* 16.

Whereas the *corrector optics* 14 may be adapted to other types of *anamorphic optical subsystems* 12, a *prismatic anamorphic optical subsystem* 12' is advantageous in not significantly changing the direction of *incident light* 16, and in being relatively simple to manufacture.

- [0028] The *corrector optics* 14 may be constructed in accordance with any of a variety of different embodiments, as described hereinbelow. The selection of a particular embodiment is dependent upon the desired characteristics of the *anamorphic optical system* 10. The *corrector optics* 14 is also adapted to provide a slight focus change (optical power) that is different in the direction of anamorphic magnification than it is in an orthogonal direction, so as to compensate for an asymmetric, somewhat astigmatic focus shift that is different in these two directions, which is generally characteristic of the aberrations of *anamorphic optical subsystems* 12. By effectively applying a cylindrical lens, or a functionally similar element, as a corrective element in combination with a slight spherical (uniform) power to the *incident light* 16 (such as through the focusing of a projection lens), this residual aberration can be sub-

stantially corrected so that the image comes into focus in both directions on the same image surface.

- [0029] Referring to *Fig. 2*, the *corrector optics* 14 comprises a *cylindrical corrector* 22, the curvature of which is exaggerated in *Fig. 2* for purposes of illustration. For example, an anamorphic compression of 25% of an image at a distance of ten (10) meters from a projection lens required a plano-convex *cylindrical corrector* 22 having a twelve (12) meter radius to bring the image into focus. A cylindrical lens in the orthogonal direction would require a concave surface. The *anamorphic optical system* 10 with a *cylindrical corrector* 22 -- and also generally for other *corrector optics* 14 arrangements -- benefits from a specific focal length of the *incident light* 16 to provide a given focal length of the *exit light* 20 with best focus. Such parameters are readily generated through the use of conventional optical design algorithms known to those of ordinary skill in the art. The curvature of the *cylindrical corrector* 22 depends upon the nature of the associated aberration to be corrected. Moreover, the associated radius of curvature is not necessarily constant, which is generally true herein when any reference is made to a cylindrical curvature or to a cylindrical lens.

- [0030] Referring to *Fig. 3*, for systems where it is desirable to

have an adjustable focal length of the *exit light* 20 it is also preferable to alter the focal length of the *corrector optics* 14 in combination with an alteration of the focal length of the *incident light* 16. The generally long distance of the corrector focal length can be exploited by introducing a thin optical window, for example, made of plastic, initially oriented as shown in *Fig. 3*, and bent into a radius by forces applied at the edges so as to form a *cylindrical window corrector* 24. When a material is bent, the two surfaces do not maintain a perfect parallel relationship and the respective radii of the surfaces therefore become slightly different, so as to induce a slight optical power. For example, a 0.5 millimeter acrylic sheet was sufficient to correct the aberrations present in an image that was anamorphically compressed by 25% using a *prismatic anamorphic optical subsystem* 12' comprising a prism pair, with a projector-to-screen distance of approximately three (3) meters. Changing the distance to the screen (the focal length of *exit light* 20), can be readily accommodated by altering the amount of curvature on the window in combination with a minor focus adjustment of the projector lens. The bending is preferably performed in the axis orthogonal to the compression axis (rotated ninety degrees around the *optic axis* 29 from

the illustrated orientation), which suggests that the bent thin window becomes relatively thinner in the center than at its edges with respect to the *incident light* 16, resulting in a negative power that is prescribed in the orthogonal direction as per the optional plano-concave (negative) corrector of the embodiment illustrated in *Fig. 1*. Accordingly, the curvature of the *cylindrical window corrector* 24 is substantially transverse to a *plane* 31 of anamorphic magnification of the *prismatic anamorphic optical subsystem* 12'.

- [0031] Referring to *Figs. 4a and 4b*, the *corrector optics* 14 may comprise a *variable corrector* 26 comprising *first* 28 and *second* 30 *anamorphic elements*, each comprising any single subelement or group of subelements exhibiting anamorphic power. Each *first* 28 and *second* 30 *anamorphic element* has an associated *direction* 32.1, 32.2 of anamorphic power, and the *first* 28 and *second* 30 *anamorphic elements* are mounted in an assembly with a mechanism by which the *first* 28 and *second* 30 *anamorphic elements* can be rotated relative to one another, thereby rotating the corresponding *directions* 32.1, 32.2 of anamorphic power relative to one another. For example, as illustrated in *Fig. 4b*, the *first* 28 and *second* 30 *anamorphic elements* can be mounted in respective *wheel structures* 34.1, 34.2 of a *counter-rotating mechanism* 35 sub-

stantially aligned with and parallel to one another, and which are adapted to be rotated with respect to one another, wherein the respective *directions* 32.1, 32.2 of anamorphic power are each oriented parallel to a common plane. For example, *facing surfaces* 36.1, 36.2 of the *wheel structures* 34.1, 34.2 may incorporate teeth, for example gear teeth, particularly conical gear teeth, or a friction surface that engage with mating teeth or a mating surface operatively connected to an *adjusting knob* 38, whereby the *variable corrector* 26 is adjusted by rotating the *adjusting knob* 38, which symmetrically counter-rotates the associated *wheel structures* 34.1, 34.2, thereby counter-rotating the *direction* 32.1, 32.2 of anamorphic power of the respective *first* 28 and *second* 30 *anamorphic elements*. The relative amount of anamorphic magnification in orthogonal directions is responsive to the *counter-rotation angle* \square of the *first* 28 and *second* 30 *anamorphic elements*. The *variable corrector* 26 provides for correcting prism errors over a wide range of focal lengths of the *incident light* 16. Moreover, the *first* 28 and *second* 30 *anamorphic elements* may advantageously comprise conventional, stress-free elements such as cylindrical lenses. The cylindrical power of the *first* 28 and *second* 30 *anamorphic elements* can be determined by opti-

mizing the optical design over the desired range of desired *exit light* 20 focal lengths in combination with a variable focal change of the *incident light* 16.

- [0032] Referring to *Fig. 5*, the *corrector optics* 14 may comprise a *variable cylindrical corrector* 40 comprising a *cavity* 42 between two *optical surfaces* 44, wherein the *optical surfaces* 44 are deformed, for example, by applying a *clamping force* 46 along *opposing edges* 48 of the *optical surfaces* 44, wherein the amount of resulting optical power of the *variable cylindrical corrector* 22 is responsive to the amount of *clamping force* 46. The *cavity* 76 is at least partially filled with an *optical fluid* 50, for example, an optical liquid such as mineral oil, that in one embodiment reacts against the *optical surfaces* 44 responsive to the *clamping forces* 46 thereby causing at least one *optical surface* 44 to deform into a cylindrical shape. Different *optical surfaces* 44 having respectively different thicknesses deform by different amounts thereby providing for different amounts of relative optical power, so that with one surface relatively thick, and the other relatively thin, a substantially plano-convex lens is formed responsive to the clamping or pressurization. For example, *first* 52 and *second* 54 *glass substrates* may be bonded to one another along a *perimeter* 56, for example, by a layer

of flexible silicone along the *perimeter* 56. In another embodiment, the deformation of the *first glass substrate* 52 may be assisted or controlled by *fulcrums* 57 between the *first* 52 and *second* 54 *glass substrates* at each end thereof.

- [0033] Referring to *Fig. 6*, the *clamping force* 46 may be generated by at least one *clamp mechanism* 59 operatively coupled to either both *opposing edges* 48, or to one of the *opposing edges* 48 provided that the other *opposing edge* 48 is retained by some other means, e.g. a frame, clip or bond. For example, the *clamp mechanism* 59 illustrated in *Fig. 6* comprises a *push bar* 61 that distributes the *clamping force* 46 across the *opposing edge* 48 being clamped. The *clamp mechanism* 57 further comprises a *cam* 63 that engages with a *follower surface* 65 in or on the *pushbar* 59, and that is rotated by a *knob* 67. As the *knob* 67 is rotated, the *cam* 63 engages the *follower surface* 65, which moves the *push bar* 61 against the *opposing edge* 48 of the *first glass substrate* 52 which generates an adjustable *clamping force* 46 thereon which is reacted by a frame (not illustrated) operatively connected to the *cam* 63 and to the *second glass substrate* 54. Accordingly, the curvature of the *first glass substrate* 52 is responsive to the *clamping force* 46, which in turn is responsive to the position of the *cam* 63.

[0034] Alternately, the *optical surfaces* 44 may be deformed by either pressurizing the *optical fluid* 50 in the *cavity* 42 to form at least one convex surface, or by evacuating the *cavity* 42 to form at least one concave surface. If the *first* 52 and *second* 54 *glass substrates* are substantially longer than they are wide, then responsive to pressurization, the deformation will be substantially greater across the *width* 58 than across the length of the deforming substrate. The *variable cylindrical corrector* 22 may be further provided with additional structure to preferentially stiffen the substrates along one direction so as to prevent bending in that direction.

[0035] Referring to *Fig. 7*, a *variable cylindrical corrector* 40.1 may be incorporated into at least one surface of a *prism* 59, wherein the *corrector optics* 14 are incorporated in the associated *prismatic anamorphic optical subsystem* 12' of the associated *anamorphic optical system* 10. Rather than using a conventional solid prism, at least one *prism* 59 of an *anamorphic optical system* 10 may, for example, comprise a pair of *flat windows* 60, for example, of glass, bonded to a *prismatic shell or frame* 62 and at least partially filled with an *optical liquid* 64. At least one *surface* 66, particularly the edge thereof, of such a *prism* 59 may include a *flexible seal* 68 and

a *clamp mechanism* 59 for applying an edge pressure so as to deform the *surface* 66, thereby providing cylindrical optical power. This obviates the need for separate *corrector optics* 14. *Flat windows* 60 that are intended to remain flat may, for example, be bonded to the *prismatic shell or frame* 62 with a relatively rigid adhesive, for example, with epoxy. The resulting relatively thick *prisms* 59, 18 can be readily adapted with *ports* 72 for at least partially filling the *prisms* 59 with *optical liquid* 64, so as to provide the variable correction feature and for reducing the cost of the associated *anamorphic optical subsystem* 12. Moreover, because the liquid volume of the *prism* 59 incorporating a *variable cylindrical corrector* 40.1 is substantially greater than that of a relatively thin, separate *variable cylindrical corrector* 40, there is less of a restriction to the local flow of fluid therein as the edge pressure is applied to the associated *optical surfaces* 44, resulting in a faster settling response of the system to a pressure setting. The *surfaces* 66 of the *prismatic anamorphic optical subsystem* 12" that preferably include variable power may be determined through optimization of the *anamorphic optical system* 10 through known optical design algorithms.

[0036] The at least one *prism* 59 at least partially filled with *optical*

fluid 50, described hereinabove, provides a cost-effective way of fabricating relatively high quality, relatively large prisms. Relatively high quality optical glass sheets are readily available at low cost, even with antireflection coatings pre-applied to the external surfaces. However, changes in atmospheric pressure and temperature can cause a differential pressure between the inside and outside of the prism that, under extreme conditions, can stress the structure thereof and, even in minor cases, can warp the *optical surfaces 44* causing aberrations in the associated image.

- [0037] One way this problem can be mitigated is by partially filling the *prism 59* with *optical fluid 50*, thereby leaving a volume -- e.g. comprising air or some other gas, e.g. nitrogen or an inert gas -- within the *prism 59* so as to provide for the change in volume of the *optical fluid 50* without causing excessive variations in pressure that could otherwise adversely distort at least one *optical surface 44* of the *prism 59*. Alternately, the *prism 59* could incorporate a vessel, or a material, therein adapted to be substantially more compliant than the *optical surfaces 44* of the *prism 59* so as to provide similar compensation.
- [0038] Alternately, referring to *Fig. 8*, this problem can be miti-

gated by incorporating a *flexible membrane* 74, e.g. neoprene or VITON®, in one end of the *prism* 59, e.g. part of a wall of the prism housing. The *flexible membrane* 74 is impermeable to the *optical fluid* 50, and is substantially more flexible than the *optical surfaces* 44, e.g. glass plates, yet not so flexible as to sag under the hydrostatic pressure of the fluid if the *prism* 59 is inverted. The *prism* 59 may optionally further incorporate a relatively small *cavity* 76 proximate to a side of the *flexible membrane* 74 opposite to the *optical fluid* 50, that is vented to atmosphere through a relatively small *orifice* 78 that is sufficiently small so as to dampen the effects of relatively rapid changes to the pressure of the *optical fluid* 50, e.g. as caused by forces on the *prism* 59, e.g. from shipping and handling, but sufficiently large to enable the *flexible membrane* 74 to compensate for relatively long term changes in pressure or temperature. It should be understood that the *flexible membrane* 74 -- with or without the *cavity* 76 and *orifice* 78 -- could alternately be incorporated in a plug that seals the associated *port* 72 through which the *prism* 59 is at least partially filled with *optical fluid* 50. For example, the plug could be adapted to thread into the *prism* 59, and could incorporate an external flange that would seal against a

surface of the *prism* 59 with an O-ring.

[0039] Whereas the *anamorphic optical system* 10 of *Fig. 7* is illustrated incorporating a *clamp mechanism* 59 for deforming at least one *surface* 66 of at least one *prism* 59, it should be understood that the at least one *surface* 66 could alternately be constructed with a single, fixed cylindrical face, and thereby provide satisfactory results for at least some applications. For example, in the common home theater projection scenario, for a vertical compression (anamorphic magnification) of approximately 25%, the cylindrical curvature of the *second surface* 19.2 of the *first prism* 18.1 was minus 6500 millimeters (concave with respect to the fluid, externally convex, as generally shown in *Fig. 5*) for a projector to screen distance of 4.5 meters. In practice, this curvature provides sufficient quality for a range of projector to screen distances between approximately 3 and 7 meters so as to substantially obviate the need for variable focusing.

[0040] Accordingly a fixed cylindrical face was created by machining the appropriate curvature into the *end plates* 79 of the *prismatic shell or frame* 62 and then bonding -- e.g. with an epoxy -- and clamping the associated originally *flat window* 60 to the curved surface. In this case, it is benefi-

cial for the stiffness of the *flat window* 60 to be sufficient to maintain the cylindrical curvature over the entire surface, while also being sufficiently flexible to form the curvature without undergoing fracture or other failure. In the case of a 6500 millimeter radius, a 1.6 millimeter thick *flat window* 60 of glass sheet provided suitable properties for a prism approximately 150 millimeters across the *second surface* 19.2.

- [0041] Moreover, whereas the *anamorphic optical system* 10 of Fig. 7 is illustrated incorporating *prisms* 59 at least partially filled with *optical fluid* 50, it should be understood that one or more *prisms* 59 could alternately be solid, e.g. constructed of one or more materials, e.g. one material, e.g. optical glass.
- [0042] Several problems that are typically associated with anamorphic optical systems are barrel-shaped distortion under image compression, and pincushion distortion under expansion, each of which increases with the amount of magnification. The combination of *corrector optics* 14 with an associated *anamorphic optical subsystem* 12 provides synergistic benefits. For example, a cylindrical lens system may be used to expand the horizontal direction of an image, creating pincushion distortion. A corrected prismatic

assembly may then be used to compress the vertical direction of the image, increasing the overall relative magnification between the horizontal and vertical directions. The two assemblies may be independently or jointly corrected for most optical aberrations. However, the distortions of each assembly, being opposite in sign, are applied against each other to minimize the net result.

- [0043] The *anamorphic optical system* 10 described herein can be used in a variety of applications that would benefit from anamorphic magnification with relatively reduced aberrations, for example, including, but not limited to, home theater projection or for transforming a laser beam -- for example, as generated by a diode laser -- from an elliptical to a circular cross-section.
- [0044] As described hereinabove, a prism assembly may be used to stretch or compress one dimension of a projected image. However, without further compensation, there can be a residual lateral chromatic aberration in the resulting image. This aberration may be reduced by pre-aberrating the image prior to entering the prism assembly.
- [0045] Depending on the angles and orientation of the *prism* 18.1, 18.2, certain characteristics in the resulting image, for example, the linearity of the vertical compression, can be

optimized, perhaps as a trade-off with respect to other characteristics. Moreover, referring to *Fig. 9*, the *prismatic anamorphic optical subsystem 12'* may be adapted to increase the anamorphic magnification by using three prisms, for example, each filled with an optical fluid as illustrated in *Fig. 8*. For example, the *prismatic anamorphic optical subsystem 12''* illustrated in *Fig. 7* can be adapted with a *third prism 18.3* before the *first prism 18.2*, wherein the *second surface 19.2* of the *first prism 18.1* is adapted to incorporate a curved refractive element as described hereinabove.

- [0046] Referring to *Fig. 10*, in another embodiment of an *anamorphic optical system 10* that pre-aberrates the image, a *projector 80* having dedicated red, green and blue image component generators is used wherein the size and position of the image of each component generator is modified to produce this pre-aberration. The *projector 80* comprises a *white light source 82*, the light from which is distributed to respective *red 84, green 86, and blue 88 image modulators* either by respective *beam splitters 90, 92* or *mirror(s) 94*, or by separate illumination of the respective *image modulator 84, 86, 88*. The particular colored light for each respective *image modulator 84, 86, 88* is either filtered before or within the respective *image modulator 84, 86, 88*. The respective

colored light from the respective *image modulators* 84, 86, 88 is then recombined -- for example, with associated *mirror(s)* 90' and *beam splitters* 92, 94' -- and projected by *projection optics* 95, e.g. a projection lens, so as to form a beam of *incident light* 16 upon the *corrector optics* 14 and *anamorphic optical subsystem* 12 as described hereinabove. It should be understood that it is beneficial for the respective beam paths from each respective *image modulator* 84, 86, 88 to the *projection optics* 95 to be generally equidistant, notwithstanding that this condition is not illustrated literally in *Fig. 8* as drawn.

- [0047] In operation, for the *anamorphic optical subsystem* 12 comprising a *prismatic anamorphic optical subsystem* 12' oriented to as to introduce aberrations along the vertical axis (Z), each component image is vertically scaled and then vertically shifted by the respective one or more *image modulators* 84, 86, 88 to compensate for the anamorphic lens lateral chromatic aberration. The vertical scaling (compression or expansion) may be performed either with a dedicated anamorphic lens at the component *image modulator* 84, 86, 88, or preferably, by prescaling the electronic image using a readily available *electronic scaling device* 96. The shifting of the respective image components of the

respective colors may also be performed by electronically shifting the image location vertically on the modulator by simply adjusting the vertical position of the modulator.

- [0048] If the respective image components of the respective colors are not shifted and scaled -- as is illustrated respectively in *Figs 11a, 12a* and *13a* -- then the corresponding image components in the composite image are not properly aligned with one another, as is illustrated in *Fig. 14a*. The respective image components in the composite image -- illustrated in *Fig. 14b* -- are properly aligned as a result of the above described scaling applied to the individual image components --illustrated in *Figs 11b, 12b* and *13b*, wherein the blue image is not compressed, the red image is vertically compressed, and the green image is vertically compressed less than the red image, so that the integrated image in *Fig. 14b* does not exhibit evidence of chromatic aberration.
- [0049] Referring to *Fig. 15*, in a second embodiment, an *electronic signal 98.1, 98.2, 98.3* to each *image component generator 100.1, 100.2, 100.3* is modified by a respective *scaler/positioner 102.1, 102.2, 102.3* to achieve the proper result by altering the size and position of each component image on its respective *image component generator 100.1, 100.2, 100.3*. The

scaling and shifting of the respective image components is in accordance with the description hereinabove. If a single modulator is used for all colors, then the component images for each color are preferably compressed and shifted electronically. As an alternative to vertical scaling symmetrically about the optical axis and shifting, each image may be scaled so that the compression is greater in one vertical location than another, thereby effectively compressing the component image toward the vertical position of least chromatic aberration.

[0050] While specific embodiments have been described in detail, those with ordinary skill in the art will appreciate that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limiting as to the scope of the invention, which is to be given the full breadth of the appended claims, and any and all equivalents thereof.

[0051] I Claim: